AD A002939

12

Best
Available
Copy

JOURNAL OF APPLIED PHYSIOLOGY
Vol. 37, No. 4, October 1974. *Printed in U.S.A.*

Indirect measurement of systolic blood pressure during $+G_z$ acceleration

(17)

FRANK JOHN FORLINI, JR.
Biodynamics Branch, Environmental Sciences Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, United States Air Force, Brooks Air Force Base, Texas 78235

TR-74-22

FORLINI, FRANK JOHN, JR. *Indirect measurement of systolic blood pressure during $+G_z$ acceleration.* J. Appl. Physiol. 37(4): 584–586. 1974.—Noninvasive determination of systolic blood pressure (Psa) during $+G_z$ acceleration is inadequate due to biological vibrations secondary to skeletal muscle straining maneuvers. By use of a Doppler ultrasonic flow probe, occlusive arterial cuff with a cuff pressure transducer (sphygmomanometer) and a long arm cast for flow probe stability, no significant difference was found between this noninvasive system and direct arterial Psa up to $+5$ G_z. Employment of such a noninvasive system is accurate and atraumatic and reduces the need for qualified professional personnel to perform arterial catheterization.

Doppler ultrasonic flow probe; automatic sphygmomanometry

DETERMINATION of systolic blood pressure (Psa) with noninvasive techniques is more desirable than arterial invasion due to vascular complications and subject discomfort associated with the latter procedure (1, 2, 9). In high, sustained $+G_z$ environments,[1] accurate determination of this physiological parameter by indirect Korotkoff sound detection becomes inadequate due to biological noise artifact induced by increased skeletal muscle straining during performance of the M-1 maneuver[2] necessary to prevent blackout and unconsciousness. This report describes a new technique utilizing a transcutaneous Doppler ultrasonic flow probe sphygmomanometer system for noninvasive determination of Psa during $+G_z$ environments. Noninvasive Psa determinations were confirmed by simultaneous invasive Psa determinations in the contralateral arm.

METHODS

Prior to instrumentation right-left arm Psa differences were elicited for each subject. Four simultaneous bilateral Psa determinations were performed on each subject by two observers utilizing standard cuff/mercury manometer techniques (4). To eliminate observer variability, each observer performed two of his four determinations on each arm. Left arm Psa was significantly higher in all subjects (F test, $P < 0.02$). Mean difference was 0.9 mmHg with a subject difference range of $+0.5$ to $+2.0$ mmHg. These differences, although statistically significant, were considered to be negligible and within the limits of the technique.

Direct arterial blood pressure. Percutaneous right radial artery catheterization under local anesthesia (2% Xylocaine; Astra Pharmaceutical Products, Inc., Worcester, Mass.) was performed with a 20-gauge Teflon catheter (Longdwel; Becton, Dickinson and Co., Rutherford, N.J.) utilizing aseptic technique. A Statham P37 miniature pressure transducer (range: 0–300 mmHg) was connected to the radial artery catheter by a 46-cm sterile hard-

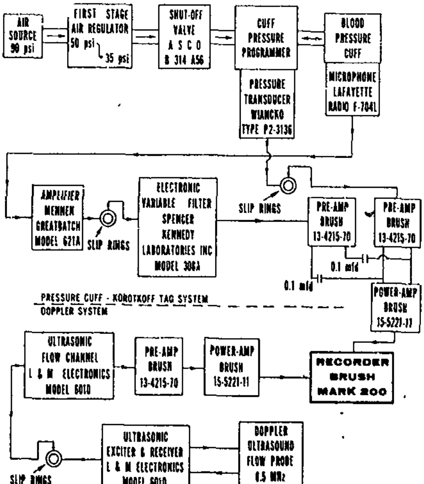

FIG. 1. Upper portion is block diagram for automatic sphygmomanometer system (with Korotkoff sound detector) as originally developed by Rogge et al. (8). Lower portion is block diagram of Doppler ultrasonic flow probe system.

wall Teflon connector (ID 0.0625 inch, OD 0.12 inch). The transducer was calibrated 0–250 mmHg with a mercury manometer. Catheter patency was maintained by frequent introduction of heparinized saline solution (3 units/ml normal saline) which was performed slowly and with a maximum of 2 ml of solution to prevent the possibility of retrograde systemic embolization (6).

Indirect Doppler/sphygmomanometer system: pressure cuff portion. A

---

[1] $+G_z$ acceleration: inertial vector in head-to-foot direction.

[2] M-1 maneuver: repeated, forceful exhalations against a partially closed glottis with vigorous tensing of skeletal musculature. Each exhalation is prolonged to 4–5 s and followed by rapid inhalation.

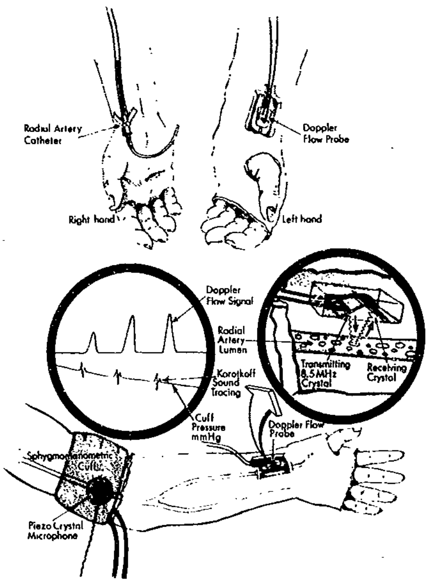

FIG. 2. Artist's conception of Doppler/sphygmomanometer instrumentation on human left arm. Long arm cast (plaster of Paris) is utilized to stabilize temporal relationship between Doppler flow probe and radial artery lumen during changing +G_z environments. Invasive measurement of systolic blood pressure was performed from the right radial artery.

standard 12 x 23 cm Velco arterial cuff (4) with a cuff pressure transducer was placed around the left upper arm for brachial artery occlusion and cuff pressure recording during bleed off. Pressure range was 0-250 mmHg with a preset electronic calibration of 210 mmHg. A piezocrystal microphone for detection of Korotkoff sounds was placed under the distal end of the cuff over the most prominent pulsation of the left brachial artery. Output of the cuff pressure transducer and microphone were amplified and superimposed for appropriate display after passage over centrifuge slip rings. The Korotkoff sound trace, although inadequate for independent Psa determination during high, sustained +G_z acceleration, was used as a marker on the cuff pressure record to visually detect the cardiac cycle associated with resumption of blood flow as detected by the Doppler ultrasonic flow probe (see below). Cuff inflation was automatic with a 34-s cycle time and a bleed-off rate of 8 mmHg/s. Figure 1 (top portion) is a block diagram of the cuff-microphone system (8).

Indirect Doppler/sphygmomanometer system: Doppler portion. A transcutaneous Doppler ultrasonic flow probe for detection of arterial flow resumption after fall of cuff pressure below brachial Psa was carefully attached with adhesive collars to the skin overlying the left radial artery. Transmission gel (Aquasonic 100, Parker Laboratories, Inc., Irvington, N.J.) was applied to each hemicrystal and the underlying skin to facilitate transmission of incident and reflected ultrasound. Crystal excitation frequency was 8.5 MHz and Doppler shift signals were received in a unidirectional flow channel (L & M Electronics, Inc., Daly City, Calif.). A bivalved plaster of Paris long arm cast with a flow probe window (Fig. 2) was utilized to prevent disturbance of the established temporal relationship between the Doppler flow probe and radial artery lumen during increased straining maneuvers. Elbow, wrist, and metacarpal joints were immobilized. Both arms were supported on full length arm rests to prevent downward movement during increased +G_z. Foam rubber padding was interposed between the left arm rest and the plaster of Paris cast to prevent transmission of spurious centrifuge capsular vibrations through the cast to the Doppler flow probe. The lower portion of Fig. 1 is a block diagram of the Doppler system.

Data acquisition. The vertical distance between the piezocrystal microphone and Statham pressure transducer was measured for calculation of the hydrostatic column during the increased +G_z environment. The Statham pressure transducer diaphragm was oriented parallel to the inertial vector to eliminate a G effect on Psa determination. Direct arterial blood pressure, Doppler flow signal, and cuff pressure with superimposed Korotkoff sounds were continuously recorded (Fig. 3). The Doppler signal was carefully monitored with headphones. The first audible Doppler shift signal after zero flow was used to determine Psa from the cuff pressure record. Although the superimposed Korotkoff sounds are not needed for determination of Psa with this method, they are useful in identifying a cardiac cycle associated with a weak audible Doppler shift signal (first momentary opening of brachial artery). In such a case, no Doppler shift is indicated on the pen recording system. A pen mark is quickly placed by the Korotkoff sound associated with the audible Doppler shift signal and serves as a permanent record of where the Doppler event occurred. Continuous direct arterial pressure was recorded and then compared to the indirectly determined Psa following hydrostatic column correction.

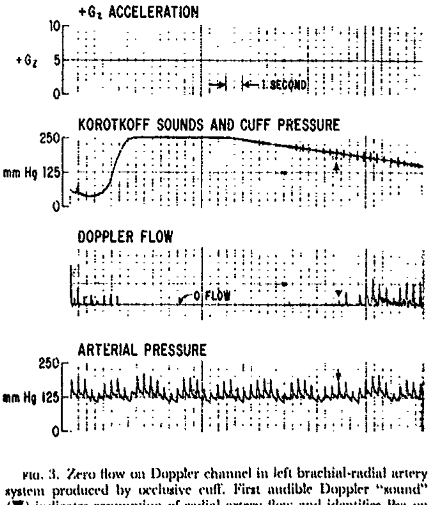

FIG. 3. Zero flow on Doppler channel in left brachial-radial artery system produced by occlusive cuff. First audible Doppler "sound" (▼) indicates resumption of radial artery flow and identifies Psa on cuff pressure record (arrow up). Simultaneous direct arterial pressure (arrow down) confirms the indirect Psa measurement. Arterial pressures are not hydrostatically correct in this figure. Note disappearance of Doppler flow signal 2 beats later with fall in arterial pressure. Korotkoff sounds appearing 2.9 s before flow resumption do not correlate with hydrostatically corrected direct arterial Psa.

TABLE 1. *Indirect (left arm) and direct (right arm) systolic blood pressure (mmHg) at various $+G_z$ levels*

G Level	Indirect Psa	Direct Psa	Significance
1 G_z	117.2 ± 3.2	117.8 ± 3.3	NS
3 G_z	139.2 ± 6.7	138.8 ± 6.4	NS
3.5 G_z	158.9 ± 7.9	158.3 ± 7.9	NS
5 G_z	191.8 ± 11.5	191.4 ± 11.9	NS
All $+G_z$ levels combined	151.8 ± 4.9	151.6 ± 4.9	NS

Psa values are means ± SE calculated from mean duplicate Psa determinations at each $+G_z$ level on 6 subjects (values are hydrostatically corrected). NS = not significant.

Indirect Psa determinations were made every 34 s during control and acceleration periods. All recordings were accomplished on a Brush model 200 direct pen recorder at 10 or 25 mm/s paper speed. Frequency response is 50 Hz. ECG rate and rhythm, anti-G suit pressure and G level were continuously monitored.

Acceleration. Six active duty male USAF personnel (age range: 21-25 yr) were exposed to rapid onset runs (1 G/s) of 3.0, 3.5, and 5.0 $+G_z$ on the USAFSAM human centrifuge. Each acceleration period was for 60 s. Adequate rest periods were afforded to allow blood pressure and heart rate to return to control levels between $+G_z$ exposures. Three subjects were instructed to intensify their straining maneuver during the +5.0 G_z acceleration in order to increase Psa above 200 mmHg. Such a maneuver simulates the muscle straining artifacts which commonly interfere with indirect Psa determination during higher $+G_z$ environments. All subjects were protected with a standard USAF CSU 12 P inflatable anti-G suit and had control of the centrifuge safety brake.

RESULTS

Table 1 displays means and standard errors for Psa as determined by the indirect Doppler sphygmomanometer method and direct arterial invasion (hydrostatically corrected) at each G level and all G levels combined. The paired *t* test was used to test for significance. No significant difference was found.

DISCUSSION

The determination of Psa by direct arterial invasion has been frequently used during exposure to dynamic G environments (5, 10). Measurements referenced to a single point within a G field (eye, heart, foot level) are accurate and continuous. Arterial invasion, however, is not a procedure without complications. Subcutaneous hematoma, retrograde air embolization, distal systemic thrombosis-embolization, pulse loss (with resultant tissue O_2 compromise), and infection are sequelae that have been encountered in cardiac catherization laboratories (1). Noninvasive methods, under most circumstances, are preferable and more conducive to subject comfort.

Until the need to study effects of high, sustained $+G_z$ environments, indirect determination of Psa by Korotkoff sound detection had been considered adequate. Narrow band-pass filtering (12–34 Hz) is employed to permit passage of the major energy components contained in Korotkoff sounds while eliminating significant portions of higher environmental frequencies (7, 8). Utilization of such techniques, however, does not eliminate biological vibratory and motion artifact produced during skeletal muscle straining maneuvers necessary during high $+G_z$ environments. Noninvasive determination of arterial pressure with ultrasound kinetoarteriography (arterial wall motion detection) as introduced by Ware (12) and confirmed with arterial invasive techniques by Kemmerer et al. (3) and Stegall et al. (11) have been reported in motionless subjects. Application of the technique for determination of arterial systolic blood pressure during low-G centrifugation by our laboratory (Biodynamics Branch USAFSAM) has shown the method to be less reliable than Korotkoff sound detection in nonstraining subjects and uninterpretable during skeletal muscle straining maneuvers. Limb restraints and multiple hemicrystals were used in the study.

In this study, employment of a Doppler ultrasound velocity flow probe (detection of flow rather than wall motion), automatic sphygmomanometer cuff, and a modified long arm cast has eliminated many of the problems associated with indirect determination of Psa during $+G_z$ acceleration. In addition, the method is atraumatic and further reduces the need for qualified professional personnel to perform arterial catheterization.

I thank Dr. Sidney D. Leverett, Jr., for his critical appraisal of this manuscript; MSgt Edward Lee, Sgt David Endt, and the USAFSAM centrifuge personnel for their many ideas and hours of labor; Dr. Phelps Crump and Mr. William Jackson of the Biometrics Branch for their invaluable statistical analysis; Mrs. Charles G. Williams, Jr. for her manuscript transcription; and Dr. H. Sandler and Mr. S. Rositano of NASA-Ames, Mountain View, Calif., for use of their Doppler ultasonic velocity flow probe system.

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 80-33.

Further reproduction is authorized to satisfy the needs of the US Government.

Author's present address: Rock Island Franciscan Medical Center, 2701 17th St., Rock Island, Ill. 61201.

Received for publication 28 January 1974.

REFERENCES

1. Braunwald, E., and H. J. C. Swan. Cooperative study on cardiac catheterization. *Circulation*, Suppl. III: 1-113, 1968.
2. Formanek, G., R. S. Frech, and K. Amplatz. Arterial thrombus formation during clinical percutaneous catheterization. *Circulation* 41: 833-839, 1970.
3. Kemmerer, W. T., R. W. Ware, H. F. Stegall, and W. Evans. Indirect measurement of human blood pressure by the Doppler ultrasonic technique. *Surg. Forum* 18: 163-165, 1967.
4. Kirkendall, W. M., A. C. Burton, F. H. Epstein, and E. D. Freis. Recommendation for human blood pressure determinations by sphygmomanometers. *Circulation* 36: 980-988, 1967.
5. Leverett, S. D., Jr., R. J. Crossley, S. J. Shubrooks, Jr., R. R. Burton, and E. D. Michaelson. *Physiologic Responses to High, Sustained +G_z Acceleration.* Brooks AFB, Texas. USAF School of Aerospace Medicine, Rept. SAM-TR-73-21. In press.
6. Lowenstein, E., J. W. Little III, and H. L. Ing. Prevention of cerebral embolization from flushing radial artery cannulas. *New Engl. J. Med.* 285: 1414-1416, 1971.
7. Rautekkus, T., J. F. Feliz and J. W. Fickes. *Frequency Analysis of Korotkov Blood Pressure Sounds Using the Fourier Transform.* Brooks AFB, Texas: USAF School of Aerospace Medicine, Rept. SAM-TR-66-8, February 1966.
8. Rogge, J. D., W. K. Brown, and C. A. Brown. *An Automatic System for the Indirect Determination and Recording of Human Arterial Blood Pressure.* Brooks AFB, Texas: USAF School of Aerospace Medicine, Rept. SAM-TR-68-25, March 1968.
9. Samaan, H. A. The hazards of radial artery pressure monitoring. *J. Cardiovascular Surg.* 12: 342-347, 1971.
10. Shubrooks, S. J., Jr., and S. D. Leverett, Jr. Effect of the Valsalva maneuver on tolerance to $+G_z$ acceleration. *J. Appl. Physiol.* 34: 460-466, 1973.
11. Stegall, H. F., M. B. Kardon, and W. T. Kemmerer. Indirect measurement of arterial blood pressure by Doppler ultrasonic sphygmomanometry. *J. Appl. Physiol.* 25: 793-798, 1968.
12. Ware, R. W. New approaches to the indirect measurement of human blood pressure. *Natl. Biomed. Sci. Instr. Symp. Instr. Soc. Am., 3rd, Galveston, Texas.* Paper BM-65, 1965.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

AD A002939

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER TR-74-220	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) Indirect measurement of systolic blood pressure during $+G_z$ acceleration	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Frank J. Forlini, Jr.	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS USAF School of Aerospace Medicine Aerospace Medical Division (AFSC) Brooks AFB, Texas	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 79300325
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE 14 Dec 1973
	13. NUMBER OF PAGES 11
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

~~This document has been~~ Approved for public release; ~~and sale; its~~ distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Doppler Ultrasonic Flow Probe
Korotkoff Sounds

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE